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Analysis of Wind Effect on the Performance of Indoor Burners

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Introduction

The purpose of this paper is to analyze the effect of wind on the performance of indoor burners (combustors), such as wood stoves, pellet stoves, gas burners, or fireplace, that take the air directly from inside the building and emits the exhaust to the environment through a chimney, stack or flue, hereafter referred to simply as a "chimney."

It is known for a long time that the rate of the exhaust gas going through a well-insulated (adiabatic) chimney is approximately proportional to the square-root of the height of the chimney. In fact, by using fluid mechanics coupled with a few simplifying assumptions, the following equation can be derived for the exhaust gas going through the chimney [1][1]:

$$V_c = \sqrt{2gy(\frac{\rho_1}{\rho_2} - 1)} \qquad (1)$$

In the above equation, V_c is the gas velocity through the chimney; g is the gravitational acceleration; y is the chimney height; ρ_1 is the density of the cool air of temperature T_1 entering the chimney; and ρ_2 is the density of the hot gas of temperature T_2 being emitted through the chimney upon combustion. Note that the above equation is valid only when there is no wind outside, and when ρ_1 is greater than ρ_2. The fact that the temperature difference (T_2-T_1) or the resultant density difference ($\rho_1 - \rho_2$) causes the exhaust gas to rise through the chimney at velocity V_c is usually referred to as the "chimney effect" or "stack effect" in scientific literature. It is a natural (not forced) convection caused by heating through combustion. From Equation 1, it can be seen that the stronger the combustion is (i.e., the larger the density ratio ρ_1 / ρ_2 is), the larger the velocity V_c becomes and the stronger the chimney effect is. The equation also shows that the velocity V_c which characterizes the chimney effect increases with the chimney height, y. More specifically, V_c is proportional to the square-root of y. This means that doubling the velocity V_c can be achieved by a four times increase in the chimney height. The foregoing analysis pertains to the case of chimney flow without wind. The case with wind blowing is to be analyzed next in a similar manner.

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[1] Numerals in [ ] represent corresponding items giv n in REFERENCES listed at the end of this paper.

Analysis of Wind Effect

Wh n wind is blowing against a building, it generates a pressure different from the ambient atmospheric pressure both on the building exterior (walls and roofs) and the interior. The pressure is considered positive when it is above the ambient pressure, and negative when it is below the ambient. The external pressure (i.e., the pressure on the exterior walls and roofs) is positive on the windward walls and the windward part of the roof of large slopes, and negative on the leeward walls and the leeward part of roofs and on flat roofs. On the other hand, the building internal pressure is usually negative unless there are dominant windward openings, such as when a windward door or a windward window is open during the wind. For this reason, the internal pressure of buildings is usually negative. More detailed discussion of the external and internal pressure of buildings can be found in [2] and [3].

For a building with large openings between rooms, such as an ordinary house or home, the internal pressure caused by wind, P_i, is approximately uniform throughout the house interior. Its magnitude is

$$P_i = P_o + \frac{C_{pi} V^2 \rho}{2} \qquad (2)$$

where P_o is the ambient atmospheric pressure; C_{pi} is the internal pressure coefficient, which is normally a negative number in the neighborhood of -0.3 [2, 3]; V is the wind velocity; and ρ is the ambient air density.

Using the same approach used in the derivation of Equation 1, for the case of wind blowing against a building the derivation can be modified as follows:

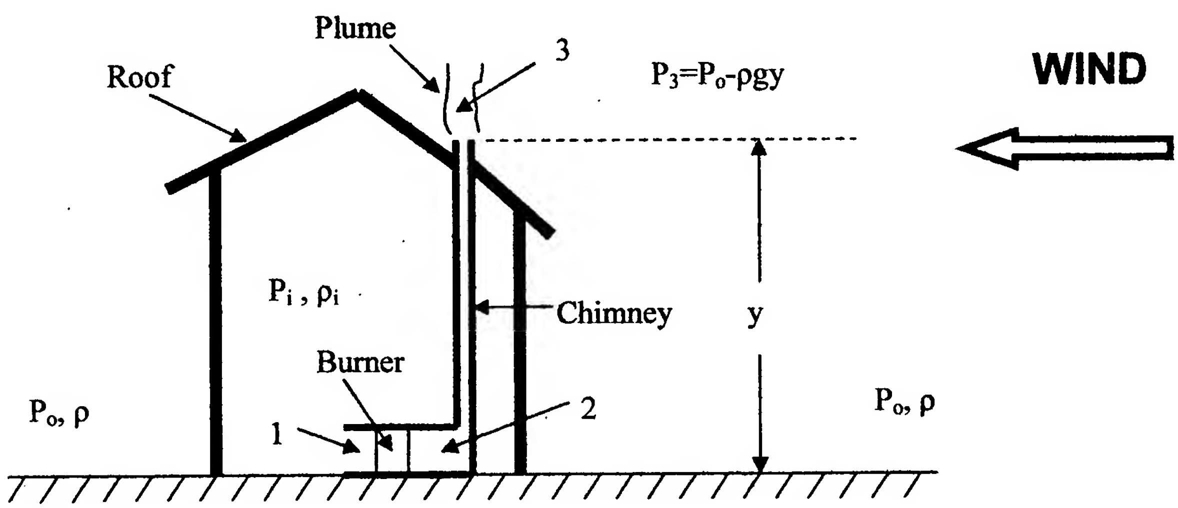

Figure 1 Analysis of wind ffects on the performance of indoor burners

Referring to Figure 1, the pressures of th air in the combustor (burner), both at the inlet of the combustor, point 1, and after combustion, point 2, are approximately the same as the building internal pressure P_i, namely $P_1 \approx P_2 \approx P_i$. Because the inlet air is at room temperature, from the equation of state of ideal gas the air density at point 1, ρ_1, must be approximately the same as the air density in the room, ρ_i. In contrast, the temperature of the combusting gas at point 2 is much higher than the room-temperature air at point 1, whereas the pressure is about the same at points 1 and 2. Consequently, from the equation of state the gas density ρ_2 must be much lower than the air density at ρ_1 (namely, $\rho_2 << \rho_1$). Furthermore, assuming only minor decrease in the temperature and the pressure of the exhaust gas from point 2 to point 3, the equation of state leads to $\rho_2 \approx \rho_3$. Therefore, use of the one-dimensional energy equation in fluid mechanics and the assumption of negligible energy loss along the chimney yields

$$\frac{V_c^2}{2} = \frac{P_2 - P_3}{\rho_2} - gy \qquad (3)$$

But, $P_2 - P_3 = P_i - P_3 = P_i - (P_o - \rho gy) = (P_i - P_o) + \rho gy$. Therefore, Equation 3 can be rewritten as

$$\frac{V_c^2}{2} = \frac{(P_i - P_o) + \rho gy}{\rho_2} - gy \qquad (4)$$

Solving for V_c yields

$$V_c = \sqrt{2gy(\frac{\rho}{\rho_2} - 1) + 2\frac{(P_i - P_o)}{\rho_2}} \qquad (5)$$

Substituting Equation 2 into Equation 5 yields

$$V_c = \sqrt{2gy(\frac{\rho}{\rho_2} - 1) + \frac{\rho}{\rho_2} C_{pi} V^2} \qquad (6)$$

Note that the second term on the right side of Equation 6, namely $C_{pi}V^2(\rho/\rho_2)$, is negative because C_{pi} is negative. Therefore, as the wind speed V increases, the velocity of the exhaust gas in the chimney, V_c, decreases. When the wind speed reaches the critical value $V = V_o = \sqrt{\frac{2gy}{C_{pi}}(1 - \frac{\rho_2}{\rho})}$, V_c becomes zero, and the chimney becomes unable to pass the exhaust gas to outside the building. Equation 6 is applicable only when the wind speed V is less than or equal to V_o. When V is greater than V_o, the direction of the flow in the chimney reverses, bringing exhaust gas into the building which is a very dangerous situation. Also, when the wind speed V is zero, the second term on the right of Equation 6 becomes zero, the ambient air density ρ becomes the same as ρ_1, and the equation reduces to Equation 1, as it should.

Conclusion

It can be concluded from the foregoing analysis that because wind usually generates a negative pressure inside buildings, wind is usually d trimental to the proper functioning of any indoor combustor. The higher the wind speed is, the less the exhaust gas can pass through the chimney. When the wind speed reaches or exceeds a critical value V_o, the exhaust gas can no longer pass through the chimney. Instead, it enters the building, causing a dangerous condition to the building occupants.

References

[1] Sabersky, R. H., Acosta, A. J., Hauptmann, E. G. and Gates, E. M., Fluid Flow, 4th Edition, Problem 3.7 (page 99) with answer on page 588, Prentice Hall, New Jersey, 1999.

[2] Liu, H., Wind Engineering: A Handbook for Structural Engineers, Chapter 4 Wind Pressure and Forces on Buildings and Other Structures, Prentice Hall, New Jersey, 1991.

[3] Liu, H. and Saathoff, P.J. "Internal Pressure and Building Safety," Journal of Structural Division, American Society of Civil Engineers, Vol. 108, No. 10, 1982, pp.2223-2234.